GLOBAL LIGHTING ASSOCIATION

Position Statement on UV Germicidal Irradiation

GUIDELINES FOR QUANTIFICATION OF AIRBORNE PATHOGEN INACTIVATION BY UVGI TECHNOLOGIES

February 2022

FOREWORD

About the Global Lighting Association

The Global Lighting Association (GLA) is the voice of the lighting industry on a global basis. GLA shares information on political, scientific, business, social and environmental issues of relevance to the lighting industry and advocates the position of the global lighting industry to relevant stakeholders in the international sphere. See www.globallightingassociation.org.

UV-C and urgent need for quantification guidelines

Ultraviolet germicidal irradiation (UVGI) air disinfection technology is an established method to reduce infection risks caused by a wide range of contagious airborne diseases. However it does raise the following questions: 1. Does it work? and 2. Is it safe?

The Global Lighting Association answered the safety question with its 2020 publication *UV-C Safety Guidelines* (reproduced by the International Electrotechnical Commission in *IEC PAS 63313*), which concludes that the technology is safe if installed correctly. GLA has reconvened the same technical task force to prepare this statement with guidelines for the quantification of airborne pathogen reduction by UVGI technologies.

TABLE OF CONTENTS

1. INTRODUCTION

Pathogens spread by touch (direct person-to-person or indirect via surface transfer), spray (ballistic droplets) and inhalation of airborne aerosols are causing diseases such as SARS-CoV-2. The spread of pathogens by touch and the transmission of droplets can be reduced by surface cleaning including washing hands, use of personal protective equipment (PPE) such as mouth masks and appropriate behaviours such as social distancing. The spread and inhalation of pathogens by aerosols can be reduced by use of medical PPE and/or air cleaning. Air cleaning can be achieved by air replacement utilising ventilation (either natural and/or mechanical) and/or air disinfection technologies such as Ultraviolet Germicidal Irradiation (UVGI) and ionisation.

UVGI air disinfection technology is an established method to reduce infection risks caused by a wide range of highly contagious airborne diseases. During the last 80 years, the capability of UVGI technology to inactivate pathogens responsible for airborne diseases such as measles, influenza and tuberculosis has been proven over and over again, as shown in studies by Wells [1] and McLean [2] which identified 74% and 90% transmission reduction in these diseases respectively. It follows that UVGI technology is also one of the key tools to reduce the level of indoor air contamination [3] and thereby contribute to improving human health in general, including during and beyond the current COVID-19 pandemic. The corresponding fundamental pathogen inactivation theory and mathematical modelling are well established and described in existing UVGI documentation.

Section 2 describes the scope of this guidance document and Section 3 illustrates the UVGI working principles of the products in scope. In Section 4, the Global Lighting Association endorses the standardisation of a microbial clean air delivery rate which can be determined in a defined test chamber, and which is an unambiguous UVGI product specification. In Section 5 it is explained how these UVGI product specifications can be used to quantify the microbial cleaning capabilities of the UVGI products in a real application/room.

The Global Lighting Association recommends this document for use as reference material by international standards development organisations such the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO).

2. SCOPE OF THIS GUIDANCE DOCUMENT

This document describes quantification of the active airborne pathogen inactivation capabilities of UVGI technologies with wavelengths in the UV-C range of 200 nm to 280 nm. It does this at product and application level.

The scope includes:

- UVGI luminaires
- UVGI air cleaners

See Section 3 for illustrative examples.

Not in scope are:

- UV-A, UV-B and 405 nm technologies
- UVGI lamps, UVGI light-sources and UVGI control-gear
- water disinfection and surface disinfection technologies
- UVGI devices which will be mounted in-duct in heating, ventilating and air-conditioning (HVAC) systems since these devices are already standardised in ISO 15714 (Method of evaluating the UV dose to airborne microorganisms transiting in-duct ultraviolet germicidal irradiation devices).
- UVGI devices combining UVGI with mechanical filters (e.g. HEPA[1] filters), chemicals and/or additives.
- ionisation air cleaning technologies
- UVGI devices intended for use in medical treatment locations such as surgical suites, laboratories and medical treatment rooms

The document does not describe UVGI safety requirements since they appear in existing international standards IEC 62471:2006 (Photobiological safety of lamps and lamp systems), IEC PAS 63313:2021 (Position statement on germicidal UV-C irradiation - UV-C safety guidelines), ISO 15858 (UV-C Devices - Safety information - Permissible human exposure), IEC 60335-2-65 (for closed UVGI technologies) and IEC 63086-1:2020 (Household and similar electrical air cleaning appliances - Methods for measuring the performance - Part 1: General requirements).

[1] High Efficiency Particulate Air

3. EXAMPLES OF UVGI OPERATING PRINCIPLES

This Section illustrates examples where no disinfection measures are taken (§3.1) and the operating principles of UVGI air cleaners (§3.2) and UVGI luminaires (§3.3)

3.1 No disinfection measures

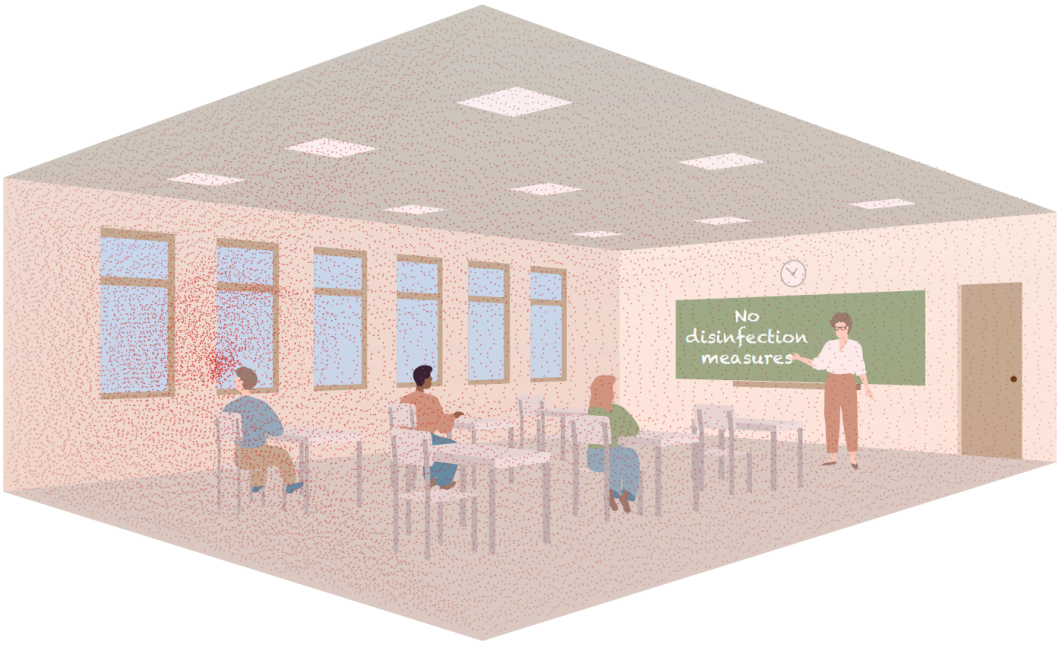

Figure 1: Illustrative example where no disinfection measures are taken

3.2 UVGI air cleaners

Figure 2: Illustrative example of UVGI air cleaner application

3.3 UVGI luminaires

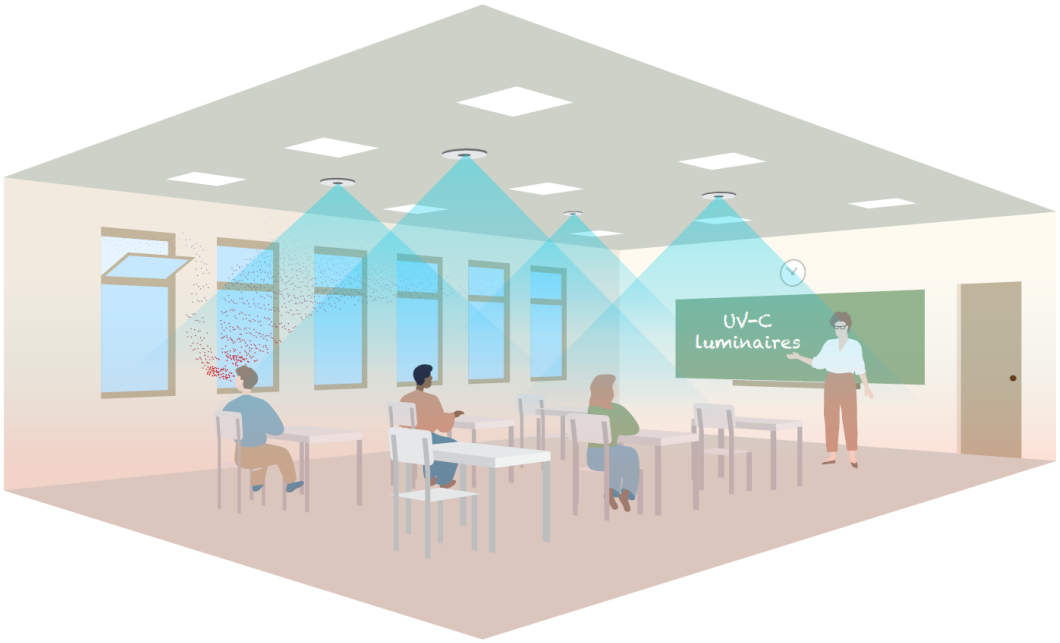

Figure 3: Illustrative example of a UVGI luminaire application

Figure 4: Illustrative example of UVGI upper-room luminaire application

4. QUANTIFICATION OF MICROBIAL CLEANING CAPABILITIES OF UVGI PRODUCTS IN A TEST CHAMBER

In the 1980s, the Association of Home Appliance Manufacturers introduced Clean Air Delivery Rate (CADR) as a standard metric for assessing the performance of air cleaners in reducing particles from air (smoke, dust, pollen etc).

GLA encourages standards development organisations to endorse the decay rate[2] method with the microbial clean air delivery rate metric ($CADR_{microbial}$) for assessing the performance of air cleaners for removing and/or inactivating airborne pathogens in air. GLA also encourages standards development organisations to standardise an equivalent decay rate method with an equivalent microbial clean air delivery rate metric ($eqCADR_{microbial}$) for assessing the performance of UVGI luminaires for inactivating airborne pathogens in air.

The $CADR_{microbial}$ of a UVGI air cleaner or the $eqCADR_{microbial}$ of a UVGI luminaire is determined by a test using nebulised and homogeneously distributed active (or surrogate) airborne pathogens inside an enclosed test chamber with a volume of at least 20 m^3 at controlled air temperature and relative air humidity. The $CADR_{microbial}$ or $eqCADR_{microbial}$ is calculated by the reduction rate of the active airborne pathogen in a defined period of time, considering the natural decay rate of the active airborne pathogen and the volume of the test chamber.

Note 1: An air mixing in the enclosed test room is required to maintain a homogeneous distribution of the airborne pathogens in the test room during the test.

Note 2: GLA recommends the usage of an active Coliphage PhiX-174 or MS2 surrogate pathogen since they are fully benign bacteriophage viruses that are well studied [4,5].

For a UVGI air cleaner test results should be reported as $CADR_{surrogate\text{-pathogen}}$ and for a UVGI luminaire test results should be reported as $eqCAD_{surrogate\text{-}pathogen}$

The final standardisation of $CADR_{microbial}$ and eq$CADR_{microbial}$ metrics should take place in the responsible standards development organisations. Further guidance for this standardisation work is provided in Annex A.

5. QUANTIFICATION OF MICROBIAL CLEANING CAPABILITIES OF UVGI PRODUCTS IN A REAL APPLICATION

Quantification of the microbial cleaning capabilities of UVGI products in a real application such as a room can be determined by scaling-up the test chamber results of Section 4 to the volume and target pathogen of the room.

Section 5.1 below lists the various reduction mechanisms for active airborne pathogens in a room, including their quantification by a decay rate. Recommended ventilation rates for different applications are given in 5.2. Determination of the number of UVGI air cleaners required to meet recommended UVGI equivalent ventilation rate in a room is given in 5.3. Determination of the number of UVGI luminaires required to meet recommended UVGI equivalent ventilation rate in a room is given in 5.4.

[2] Alternative test methods, such as steady state methods, are the subject of ongoing research

5.1 Reduction mechanism for active airborne pathogens in a room and their generic quantification

Reduction of active airborne pathogens in a room can be achieved by:

- Dilution of the active airborne pathogens by conventional (natural and/or mechanical) fresh-air ventilation, quantified by a decay rate called the ventilation rate, with the unit $ACH_{fresh\text{-}air}$
- Natural decay of the active airborne pathogens, quantified by a decay rate called the natural-decay rate, with the unit $ACH_{natural\text{-}decay}$
- Inactivation of the active airborne pathogens by engineering methods such as UVGI, quantified by a decay rate called the equivalent ventilation rate, with the unit $eqACH_{UVGI}$[3]
- A combination of the above, quantified by the total ventilation rate, with the unit ACH_{tot}.

Note: In general [6], the overall ventilation rate (ACH_{tot}) is the sum of the ventilation rate ($ACH_{fresh\text{-}air}$), the natural-decay rate ($ACH_{natural\text{-}decay}$) and the equivalent ventilation rate of the UVGI technology ($eqACH_{UVGI}$).

In general, the reduction is expressed in a decay rate with the unit Air Changes per Hour (ACH) in h^{-1}. The relationship is given in Equation 1.

$$Decay\ Rate = \frac{-60 \ln(N_t/N_0)}{t} \qquad \text{(Equation 1)}$$

Where:

N_t, is the number of active airborne pathogens after t minutes
N_0 is the initial number of active airborne pathogens at t = 0 minutes
t is time in minutes

Note 1: A decay rate of 1 *ACH* equals a 63.2% airborne pathogen reduction in one hour.

Note 2: The above formulas assume that no further pathogen generation source is present in the room.

Note 3: The exponential decay of a microbial population in response to UV can be subject to a slight delay, also known as 'shoulder effect'. In many cases it can be neglected, especially for susceptible microbes or for high UV doses.

[3] In the technical literature, equivalent air changes per hour is variously abbreviated as *eACH, ACHeq* or *EAC*.

The relation and inverse relation between the reduction levels and reduction times on the one hand, and the decay rates (*ACH*) on the other, are given in Table 1 and Table 2 respectively.

Decay rate (*ACH) in* h^{-1}			
Reduction time [min]	Reduction level		
	90% (Log 1)	99% (Log 2)	99.9% (Log 3)
10	13.8	27.6	41.4
20	6.9	13.8	20.7
30	4.6	9.2	13.8
40	3.5	6.9	10.4
50	2.8	5.5	8.3
60	2.3	4.6	6.9

Table 1: Relation between reduction levels and reduction times, and the decay rates

Note: A log reduction is a measure of how thoroughly a decontamination process reduces the concentration of a contaminant. It is defined as the common logarithm of the ratio of the levels of contamination before and after the process, so an increment of 1 corresponds to a reduction in concentration by a factor of 10. So for example, a 0-log reduction is no reduction at all, while a 1-log reduction corresponds to a reduction of 90 percent from the original concentration, and a 2-log reduction corresponds to a reduction of 99 percent from the original concentration (source: Wikipedia).

Reduction time [min]			
Decay rate (ACH)	Reduction level		
	90% (Log 1)	99% (Log 2)	99.9% (Log 3)
1	138	277	415
2	69	138	207
3	46	92	138
4	35	69	104
5	28	55	83
6	23	46	69
7	20	40	59
8	17	35	52
9	15	31	46
10	14	28	41
11	13	25	38
12	12	23	35
13	11	21	32
14	10	20	30
15	9	18	28
16	9	17	26
17	8	16	24
18	8	15	23
19	7	15	22
20	7	14	21
25	6	11	17
30	5	9	14
35	4	8	12
40	3	7	10
45	3	6	9
50	3	6	8

Table 2: Relation between decay rates and reduction levels and reduction times

5.2 Recommended ventilation rates

The recommended total ventilation rate in a room ($ACH_{tot,\ required}$) varies according to application and depends on the required reduction level and reduction time for the airborne pathogens.

To reduce the contamination risk of viral infections like influenza, tuberculosis and SARS-CoV-2 in buildings, GLA recommends the decay rates of Table 3 during a viral outbreak. These recommendations are based on references [7,8].

Application	Recommended total ventilation rate ($ACH_{tot,\ required}$)	Recommended fresh-air ventilation rate ($ACH_{fresh\text{-}air}$)	Natural-decay rate ($ACH_{natural\text{-}decay}$)	Required UVGI equivalent ventilation rate ($eqACH_{UVGI}$)
Buildings with vulnerable people (such as hospitals, elderly care)	≥ 15	3	0	≥ 12
Buildings inhabited by many people for extended periods (such as offices, shops, schools)	≥ 10	3	0	≥ 7
Other buildings	≥ 6	2	0	≥ 4

Table 3: Recommended decay rates per application

Note 1: Above recommendations apply to the applicable areas/rooms in the building

Note 2: Above fresh-air ventilation rates are always recommended since fresh-air ventilation serves multiple purposes other than dilution of airborne pathogens, including removal of harmful gasses such as CO2, control of humidity levels (including condensation prevention) and reduction of undesirable odours.

Note 3: Key parameters driving the natural decay rate are ambient temperature, relative humidity and ambient UV-index. In the technical literature, natural decay rates reported for SARS-CoV-2, at UV-index 0, typically range from 0.2 to 2 $ACH_{natural\text{-}decay}$. However by setting the natural decay rate to zero, a worst-case situation is emulated.

5.3 UVGI air cleaner - relationship between required UVGI equivalent ventilation rate and $CADR_{surrogate\text{-}pathogen}$

As a first order approach, the number of UVGI air cleaners needed to achieve the required UVGI equivalent ventilation rate of Section 5.2 in an arbitrary room with volume V depends on the $CADR_{surrogate\text{-}pathogen}$ of the UVGI air cleaner and can be determined with Equation 2.

$$\#\ of\ UVGI\ air\ cleaners = \frac{eqACH_{UVGI} \cdot V}{CADR_{surrogate-pathogen}} \cdot \frac{k(\lambda)_{surrogate-pathogen}}{k(\lambda)_{target\ pathogen}} \qquad \text{(Equation 2)}$$

where:

# of UVGI air cleaners	is number of UVGI air cleaners needed to achieve the required UVGI equivalent ventilation rate in the room
$eqACH_{UVGI}$	is required UVGI equivalent ventilation rate (Section 6.2) in h^{-1}
V	is volume of the room in m^3
$CADR_{surrogate\text{-}pathogen}$	is CADR of the UVGI air cleaner according to the standards and testing described in Section 5 in m^3/h

k(λ)	is spectral susceptibility factor of airborne pathogens (m^2/J) as given in Table 4

Note: Equation 2 does not consider application details, including objects within the space and non-uniform placement of air cleaners.

In addition, the single pass efficacy (η) of the UVGI compartment of the UVGI air cleaner is recommended to be $\eta \geq 0.95$ at all airflow settings (Q_m) to avoid cross contaminations by (horizontal) airflows across the room induced by airflow of the UVGI air cleaner.

The single-pass efficacy, also known as removal rate, (η) of the UVGI compartment of a UVGI air cleaner can be determined by Equation 3.

$$\eta = \frac{CADR_{surrogate-pathogen}}{Q_m} \qquad \text{(Equation 3)}$$

where:

Q_m	is volumetric flow rate of air through the system in cubic metres per second (m^3/h)

5.4 *UVGI luminaire - relationship between required UVGI equivalent ventilation rate and $eqCADR_{surrogate-pathogen}$*

As a first order approach, the number of UVGI luminaires needed to achieve the required UVGI equivalent ventilation rate of Section 5.2 in an arbitrary room with volume V and a certain target pathogen depends on the $eqCADR_{surrogate-pathogen}$ of the UVGI luminaire and can be determined by Equation 4.

$$\#\ of\ UVGI\ luminaires = \frac{eqACH_{UVGI} \cdot V}{eqCADR_{surrogate-pathogen}} \cdot \frac{k(\lambda)_{surrogate-pathogen}}{k(\lambda)_{target\ pathogen}} \qquad \text{(Equation 4)}$$

where:

# of UVGI luminaires	is number of UVGI luminaires needed to achieve the required UVGI equivalent ventilation rate in the room
$eqACH_{UVGI}$	is required UVGI equivalent ventilation rate (Section 5.2) in h^{-1}
V	is volume of the room in m^3
$eqCADR_{surrogate-pathogen}$	is *eqCADR* of the UVGI luminaire as determined in Section 4 in m^3/h
k(λ)	is spectral susceptibility factor of airborne pathogens (m^2/J) as given in Table 4

Note: Equation 4 does not consider application details including room/surface reflection, objects within the space and non-uniform placement of luminaires.

The classification and spectral susceptibility factors, *k(λ)*, of some actual airborne pathogens at a relative humidity (*RH*) below 68% are listed in Table 4.

UCGI wavelength λ in nm	Airborne pathogen	Classification	$k(\lambda)$ in m^2/J	Source
254	Coliphage PhiX-174	Non-enveloped DNA virus	0.620	ISO 15714
	MS-2	Non-enveloped RNA virus	0.380	ISO 15714
	SARS-CoV-1	Enveloped RNA virus	0.377	Walker
	SARS-CoV-2	Enveloped RNA virus	0.377	Beggs
	Influenza A (H1N1)	Enveloped RNA virus	0.270	Kowalski
	Tuberculosis (TBC)	Bacteria	0.472	ISO 15714
222	Coliphage PhiX-174	Non-enveloped DNA virus		
	MS-2	Non-enveloped DNA virus		
	SARS-CoV-2	Enveloped RNA virus	0.410[4] - 0.590[5]	Brenner
	Influenza A (H1N1)	Enveloped RNA virus	0.180	Brenner
	Tuberculosis (TBC)	Bacteria		

Table 4: Classification and spectral susceptibility factors, *k(λ)*, of some actual airborne pathogens

Note 1: More spectral susceptibility factors are given by Kowalski [4] and standard ISO 15714 (Method of evaluating the UV dose to airborne microorganisms transiting in-duct ultraviolet germicidal irradiation devices)

Note 2: Spectral susceptibility factors at a relative humidity above 68% are given by Kowalski [4]

Note 3: Missing spectral susceptibility factors in Table 4, *k(λ)*, are a subject for research

[4] Alpha coronavirus (HCoV-229E)

[5] Beta coronavirus (HCoV-OC43)

6. TERMS AND DEFINITIONS

Ultraviolet germicidal irradiation (UVGI)

Method for disinfection of air, water and object surfaces that uses radiation with a wavelength in the range 200 nm to 280 nm to kill or inactivate microorganisms and viruses

Note: UV irradiation with a wavelength of 200 nm to 280 nm can cause damage to the DNA or RNA of the microorganisms or viruses.

[Source: ISO 15714:2019, 3.1.5 modified by lowering 240 nm to 200 nm and extended to viruses]

UVGI air cleaner

Electrically powered household, or similar, appliance that employs UVGI technologies to inactivate one or more types of airborne pathogens using a forced air flow through a closed UVGI compartment.

[Source: IEC 63086-1 modified]

UVGI luminaire

Apparatus which distributes, filters or transforms UVGI from at least one UVGI source and which includes all parts necessary for fixing and protecting the UVGI source and, where necessary, circuit auxiliaries together with the means for connecting them to the power supply.

[Source: IEC 60050-845; 845-30-001: 2020 modified]

UVGI upper-air luminaire

UVGI luminaire mounted underneath room ceilings with UVGI directed to the upper part of the room with adjustable louvers to keep UVGI above eye and head level.

[Source: ISO 15858: 2016 modified]

7. REFERENCES

[1] Wells WF, Fair MG. “Viability of B. coli exposed to ultra-violet radiation in air”, Science, Volume 82, Issue 2125, pp. 280-281, 1935

[2] McLean, R.L., “The effect of ultraviolet radiation upon the transmission of epidemic influenza in long-term hospital patients”, American Review of Respiratory Diseases 83(2): 36–8, 1961

[3] Anca Maria Moldoveanu, “Biological Contamination of Air in Indoor Spaces”, Current Air Quality Issues, IntechOpen, DOI: 10.5772/59727, 2015

[4] W. Kowalski, “Ultraviolet Germicidal Irradiation Handbook, UVGI for Air and Surface Disinfection”, 2009

[5] Yoram Gerchman, “UV-LED disinfection of Coronavirus: Wavelength effect”, Journal of Photochemistry and Photobiology, Volume 212, 2020

[6] Shelly Miller, “EFFICACY OF ULTRAVIOLET IRRADIATION IN CONTROLLING THE SPREAD OF TUBERCULOSIS”, CDC/NIOSH report 2002

[7] IES-CR-2-20-V1-6d

[8] https://www.cdc.gov/infectioncontrol/guidelines/environmental/appendix/air.html

ANNEX

Determination of CADR or eqCADR of UVGI product

As stated in Section 4, the Global Lighting Association encourages standards development organisations (SDOs) to endorse the decay rate method with $CADR_{microbial}$ or $eqCADR_{microbial}$ metrics for airborne pathogen removal and/or inactivation performance assessment of UVGI air cleaners and UVGI luminaires respectively.

This informative Annex provides the basic steps for $CADR_{microbial}$ or $eqCADR_{microbial}$ determination. The measurement details must be worked out by the responsibleSDOs. GLA anticipates that SDOs may improve the steps outlined in this informative annex and welcomes enhancements in test efficiency, accuracy, repeatability and reproducibility.

UVGI products to be tested are referred to in this Annex as device under test (DUT).

Step 1: Pathogen selection and test setup

1.1 Select target pathogen, or a surrogate pathogen with comparable UVGI susceptibility to the target pathogen.
1.2 If applicable, apply burn-in time of the DUT as prescribed by the manufacturer.
1.3 Select an enclosed test chamber with:
- defined volume of test room
- defined UV-C reflectance (%) of walls, floor and ceiling
- controlled air temperature
- controlled relative air humidity.

1.4 Install the DUT in the selected enclosed test chamber following manufacturer's installation instructions and approximate the intended application.

Step 2: Determine natural decay rate without operating the DUT

2.1 Close the test-chamber and control and record air temperature and relative humidity inside the test-chamber.
2.2 Nebulise the test-chamber with a quantified initial concentration colony forming units (CFU), N_0 (CFU/m^3), of the selected pathogen using a calibrated nebuliser.
2.3 Determine the measurement time (t) to assure a good natural decay value.

Note: The standard should include methodology for determining measurement times that assure good natural decay value - for example, with specific standard times and/or a standardised approach for determining test-specific times.

2.4 Activate the test-chamber's stirring fan to assure a homogeneous pathogen concentration in the test chamber

Note: To achieve an initial homogenous mixing of the pathogen in the test chamber, a period of mixing before step 2.5 is required. Any additional mixing throughout the test should be carefully specified by the SDO to ensure consistent and unbiased results.

2.5 Take a sample at measurement time t.

Note: The standard should standardise the sampling method (quantity of samples, duration etc.) in a manner that best represents conditions throughout the chamber and be repeatable and reproduceable.

2.6 Determine the concentration CFU of the pathogen, Nt (CFU/m3), at time t.

2.7 Calculate the natural decay rate with Equation 4.

$$ACH_{natural\ decay} = (60/t)(\ln N_0/N_t) \qquad (4)$$

where:

t is measurement time at time point t in minutes

Nt is CFU concentration of the pathogen at time point t, in CFU/m3

N_0 is initial CFU concentration of the pathogen, in CFU/m^3

2.8 Deactivate the chamber's stirring fan.

2.9 Ventilate/disinfect the test-chamber.

Step 3: Determine decay rate of the pathogen when DUT is operating

3.1 Activate the DUT and, if applicable, apply the stabilisation time of the DUT as prescribed by the manufacturer, and nebulise the test-chamber with a quantified initial concentration CFU, N_0 (cfu/m^3), of the selected pathogen using a calibrated nebuliser.

3.2 Determine the measurement time (*t*) to assure a good natural decay value.

Note: The standard should include methodology for determining measurement times that assure good natural decay value - for example, with specific standard times and/or a standardised approach for determining test-specific times.

3.3 Activate the test-chamber's stirring fan to assure a homogeneous pathogen concentration in the test chamber

Note: To achieve an initial homogenous mixing of the pathogen in the test chamber, a period of mixing before step 3.5 is required. Any additional mixing throughout the test should be carefully specified by the SDO to ensure consistent and unbiased results.

3.4 Take a sample at measurement time *t*.

Note: The standard should standardise the sampling method (quantity of samples, duration, etc.) in a manner that best represents conditions throughout the chamber and be repeatable and reproduceable.

3.5 Determine concentration CFU of the pathogen, Nt (CFU/m3), at time t.

3.6 Calculate total decay rate, $(eq)ACH_{total}$, with Equation 5.

$$(eq)ACH_{total} = (60/t)(\ln N_0/N_t) \qquad (5)$$

where:

t is measurement time at time point t in minutes

N_t is CFU concentration of the pathogen at time point *t,* in CFU/m^3

N_0 is initial CFU concentration of the pathogen, in CFU/m^3

3.7 Deactivate DUT and the chamber's stirring fan.

3.8 Ventilate/disinfect test-chamber and open it.

Step 4: Calculate the $CADR_{surrogate}$ or $eqCADR_{surrogate}$ value

4.1 Calculate UVGI decay rate, $(eq)ACH_{UVGI}$, according to:

$$(eq)ACH_{UVGI} = ACH_{total} - ACH_{natural\ decay}$$

4.2 Calculate (equivalent) clean air delivery rate according to:

$$(eq)CADR_{surrogate} = (eq)ACH_{UVGI} \times V_{test}$$

Step 5: Reporting

5.1 Report *(eq)CADR*$_{surrogate}$ in (m^3/h) at each tested configuration

5.2 Report test condition details such as:

- test laboratory details such as: name, location, date, operator.
- test chamber details such as:
  - volume of the test-chamber, V_{test} in m^3, and its length, width, and height in m
  - UV-C reflectance (%) of the test-chamber walls, floor, and ceiling
  - selected pathogen or surrogate pathogen and its susceptibility factor, *k(λ),* in m^2/J
  - initial CFU concentration of the pathogen, in CFU/m^3
  - temperature, humidity
  - device mounting location and mounting details including photographs
  - pre-mixing fan airflow and in-test mixing airflow
  - time of overall test and sampling times
  - nebuliser details (particle sizes, locations, timing etc.)
  - sampling locations, time, sampling method/equipment, details on method of analysis
  - chamber ventilation details that could impact interpretation of the test including air filters
  - initial and during test mixing fan details (airflow) and locations
  - chamber air clean-up method and disinfection method

5.3 Report DUT details such as:

- manufacturer
- DUT type and model number
- voltage in V, and power in W, and air flow settings in m^3/h
- peak wavelength(s) (*λ*) in nm
- inclusion of pre-filter (if any)